Experimental Study on Mechanical Properties of Geopolymer Concrete

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***Abstract—* Normally water is the most used material in worldwide. Next to the water is concrete which is made up of cement, water and aggregates. Ordinary Portland cement which generate more amount of carbon dioxide in the atmosphere which much polluted the atmosphere. The geopolymer technology could reduce the CO_2 emission to the atmosphere caused by cement industries, thereby reducing the global warming. The amount of energy consumes for the production of cement is more. Now a day's alternative material for cement like silica fume, metakaolin, etc. but the basic one is fly ash. In our study we are discussed about the geo polymer concrete whereas it is an innovative construction material, which produces from some of chemical actions of inorganic molecules. Everyone knows fly ash is product from coal which is obtained from the power plant and it is a largely available material in India. Silica and alumina in the fly ash is rich which produce alumina silicate gel that act as a binding material of the concrete. Fly ash play a vital role for the alternative construction material to the ordinary Portland cement. In this paper we discussed the properties and the applications of the geopolymer Concrete**

Keywords: Fly ash, ordinary Portland cement, Geopolymer concrete, Alumina silicate gel, Applications.

I. INTRODUCTION

Today sustainability as got top priority in construction industry. In the present study the recycled plastic where used to prepare the coarse aggregates thereby providing a sustainable option to deal with the plastic waste. Collection, hauling and disposal of plastic bag waste creates an additional environmental impact. There are many recycling plants across the world, but as plastic are recycled, they lose their strength with the number of recycling.

So, this plastic will end as landfill. Most of the failures in the concrete structure occurs due to the failure of concrete by crushing of aggregates. Plastic coarse aggregates (PCA) which have low crushing values will not crushed not as easily as stone aggregates. These aggregates are also lighter in weight compared to the stone aggregate. Since a complete substitution for natural coarse aggregate (NCA) was not found feasible, a partially substitution with various percentage of PCA was done. Both volumetric and grade substitution was employed in this investigation.

Geopolymeric concrete was superior to Ordinary Portland concrete in terms of heat and fire resistance, as the Ordinary Portland concrete experienced a rapid deterioration in compressive strength at 300°C, whereas the geopolymeric concrete were stable up to 600°C. It has also been shown that compared to Ordinary Portland concrete, geopolymeric concrete has extremely low shrinkage.

The presence of alkalis in OPC could generate dangerous Alkali-Aggregate Reaction. However, the geopolymer concrete is safe from that phenomenon even with higher alkali content. Transition zone is responsible for developing crack in the concrete. The main advantage of the geopolymer concrete is that it does not have any transition zone.

II. MATERIAL INVESTIGATION

A. Fly ash

Fly ash is the byproduct of coal combustion in power plants. Fly ash obtained from Ennore Thermal power plant, falls in the category of class F grade has been used for entire experimental work.

The total quantity of fly ash required was approximately estimated, brought and stored in an air tight container. The physical properties of the fly ash were tested in accordance with IS 1727-1967 and the results are tabulated in Table 1.The chemical composition of fly ash are given in Table 2.

TABLE 1
PHYSICAL PROPERTIES OF FLY ASH

Sl. No	Property	Value
1	Specific gravity	2.13
2	Fineness, Percentage passing on 150 micron sieve	99.6%
3	Fineness, Percentage passing on 90 micron sieve	98.1%

TABLE 2
CHEMICAL COMPOSITION OF FLY ASH

Components	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O
% by mass	56.77	31.88	2.82	2.77	0.78	2.39	0.68	1.96

B. *Rice Husk Ash (RHA)*

The rice husk ash has good reactivity when used as a partial substitute for cement. Locally available rice husk was incinerated in an electric box furnace (laboratory type) at 500°C-120 minutes duration for the production of rice husk ash. The physical properties and chemical composition of Rice husk ash are presented in Table 3.

TABLE 3
PHYSICAL PROPERTIES & CHEMICAL COMPOSITION OF RHA

Property	Value
Physical Properties	
Specific gravity	2.19
Fineness passing 45µm (%)	99.5
Blaine's fineness (cm^2/g)	22,260
Colour	White
Chemical Analysis (%)	
Silicon dioxide (SiO_2)	89.47
Ferric oxide (Fe_2O_3)	0.62
Calcium oxide (CaO)	2.69
Aluminum oxide (Al_2O_3)	Traces
Magnesium oxide (MgO)	1.16
Sulphur oxide (SO_3)	0.93
Sodium oxide (Na_2O)	2.09
Potassium oxide (K_2O)	0.83
Loss on ignition	2.27

C. *Alkaline solution*

A combination of sodium silicate and sodium hydroxide solution is used as alkaline solution for fly ash activation. The sodium silicate solution A53 grade, with SiO_2 to Na_2O ratio by mass approximately 2 (Na_2O = 14.7%, SiO_2=29.4% and water 55.9% by mass) is brought in solution form and used for the entire experimental work. The sodium hydroxide solids with 97-98% purity are bought in pellet form and dissolved in water to make a solution with the required concentration. The preparation procedure for 8M sodium hydroxide solution is as follows.

The sodium hydroxide (NaOH) solution with a concentration of 8M consists of 8x40 = 320 grams of NaOH solids (in pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 262 grams per kg of NaOH solution of 8M concentration. Similarly, the mass of NaOH solids per kg of the solution for other concentrations were measured as 10M: 314 grams, 12M: 361 grams, 14M: 404 grams, and 16M: 444 grams. Once the sodium hydroxide solution is prepared, it is mixed with the sodium silicate solution and kept for 24 hours before cube casting. In this project work, molarity of sodium hydroxide solution is maintained as 8M and the ratio of sodium silicate to sodium hydroxide solution is maintained as 2.5.

D. *Coarse Aggregate*

Locally available crushed granite stone aggregate of 20mm maximum size was used as coarse aggregate. Aggregate passing through 20mm sieve and retained on 4.75mm sieve was used for casting of concrete specimens. Aggregates are tested as per IS 2386-1963 and the results pertaining to the properties and sieve analysis are presented in Tables 4 & 5. The gradation curve for coarse aggregate is shown in Fig 1.

TABLE 4
PHYSICAL PROPERTIES OF COARSE AGGREGATE

Sl.No	Description	Quantity
1	Specific gravity	2.73
2	Fineness Modulus	9.24
3	Water absorption	2%
4	Bulk Density	1650Kg/m^3

TABLE 5
SIEVE ANALYSIS OF COARSE AGGREGATE

IS Sieve Size	%Weight retained	Cumulative weight retained (%)	Cumulative weight passing (%)
20mm	45.0	45.0	55
16mm	38.0	83.0	17
12.5mm	15.0	98.0	2
10mm	1.35	99.35	0.65

4.75mm	0.05	99.40	0.60

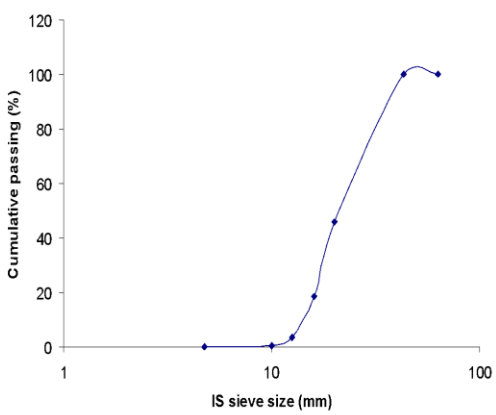

Fig 1 Gradation curve for coarse aggregate

E. Fine Aggregate

Locally available river sand was used in this investigation as fine aggregate. Fine aggregate was tested as per IS 2386-1963 and the results pertaining to the properties and sieve analysis are presented in Tables 6 & 7. The gradation curve for fine aggregate is shown in Fig 2.

TABLE 6

PHYSICAL PROPERTIES OF FINE AGGREGATE

Sl.No	Description	Quantity
1	Specific gravity	2.56
2	Fineness Modulus	2.49
3	Water absorption	1%
4	Bulk Density	1550 Kg/m^3

TABLE 7

SIEVE ANALYSIS OF FINE AGGREGATE

IS Sieve Size	%Weight retained	Cumulative weight retained (%)	Cumulative weight passing (%)
4.75mm	1.15	1.15	98.85
2.36mm	0.6	1.75	98.25
1.18mm	20.85	22.6	77.4
600µm	25.55	48.15	51.85
300µm	29.75	77.9	22.1
150µm	20.5	98.4	1.6

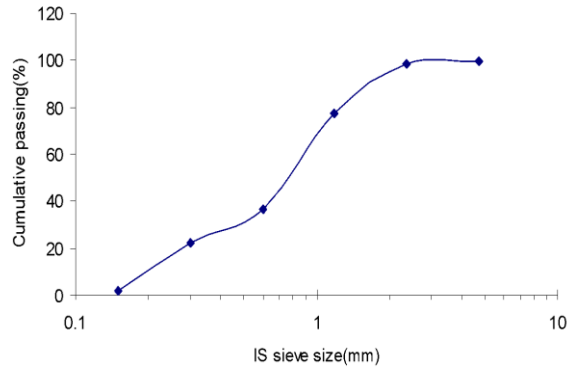

Fig 2 Gradation curve for fine aggregate

F. Chemical Admixtures

Sulphonated naphthalene formaldehyde condensate based-super plasticizer was used as water reducing agents in order to improve the workability of fresh geopolymer concrete. It is a dark brown free flowing liquid containing 42% of solids.

G. Water

Ordinary portable water available KCG campus was used for the entire experimental investigation. The total mass of water is the sum of the mass of water contained in the sodium silicate solution, the mass of water in the sodium hydroxide solution and the mass of extra water, if any contained in the mixture.

III. MIX PROPORTIONING

The mixture design of low–calcium fly ash based geopolymer concrete for alkaline to fly ash ratio by mass as 0.3.

In order to proportion geopolymer concrete, it has been decided in this investigation to use two replacement of RHA (5% & 10%). Four concrete mixtures have been considered in this work. Alkaline solution / fly ash ratio was varied as 0.30 and 0.45. The mix proportion details and ratios are given in Tables 8 & 9.

TABLE 8

MIX PROPORTION PER m^3 OF GEO POLYMER CONCRETE

Binder composition	Fly ash%	95	90	95	90
	RHA %	5	10	5	10
Alkaline solution /fly ash (by mass)		0.30	0.30	0.45	0.45
Ingredient contents of concrete, kg/m^3					
Coarse aggregate		1344	1344	1344	1344
Fine aggregate		576	576	576	576

Fly ash	350.55	332.10	314.45	297.90
RHA	18.45	36.90	16.55	33.10
Sodium hydroxide solution	32	32	43	43
Sodium silicate solution	79	79	106	106
Super plasticizer	1.70	1.75	1.40	1.50
Water to geopolymer ratio	0.28	0.28	0.29	0.29
Extra water added(litre/m^3)	49.6	49.6	24	24

TABLE 9
MIX PROPORTION OF CONCRETE MIXES

Binder		Fine aggregate	Coarse aggregate	Ratio of activator solution to binder by mass
Fly ash	RHA			
0.95	0.05	1.4	3.25	0.3
0.90	0.10			
0.95	0.05	1.48	3.45	0.45
0.90	0.10			

IV. EXPERIMENTAL SCHEME

As per the mix proportions, materials such as fly ash and aggregates were taken and thoroughly mixed in dry condition for about three minutes. The alkaline solution that was prepared one day prior to usage along with super plasticizer and extra water was added into the blend and mixed for about four minutes. The fresh geopolymer concrete was light in colour and shiny in appearance. After mixing, concrete is then smoothly transferred into moulds in three stages and compacted well and the top surface is leveled with a trowel. Totally 108 specimens were prepared to study the compressive strength of geoploymer concrete. The specimens are covered with polythene sheets to avoid desiccation. As soon as the specimens are casted, they are kept in oven for curing. After 24 hours, the specimens kept for ambient curing are demoulded and kept at ambient laboratory conditions.

V. RESULT AND DISCUSSION

A. Compressive strength

Compressive strength of Geopolymer concrete was found out at the ages of 7, 14, and 28 days. Three cubes were crushed at each age to get the average. The compressive strength at various ages for different curing conditions, alkaline solution to binder ratio was presented in Tables 10 & 11. The compression test result reveals that compressive strength of geopolymer concrete ranged from a minimum of 2.74MPa to a maximum of 30.15MPa. The results show that the strength development is related to all the three variables that were manipulated in this experiment alkaline solution to fly ash ratio, RHA replacement & curing conditions.

Effect of Curing Conditions on strength

The variations of compressive strength with age for various curing conditions are shown in Fig 3,4,5,6 and are tabulated in Tables 12 & 13. Compressive strength of oven cured specimens is more than that of ambient cured specimens irrespective of age, alkaline solution to binder ratio & RHA replacement. In ambient curing, compressive strength significantly increased with age upto 28 days. Compressive strength of ambient cured specimens at 7 and 14 days was about 20% and 36.62% of 28 days strength respectively. In oven curing, rate of increase in compressive strength was not significant beyond 7 days. Rate of increase in compressive strength at 28 days was about 24% and 12% with respect to 7 and 14 days respectively. Compressive strength of oven cured specimens at 7 days was about 7.5 times higher than that of ambient cured specimens. Compressive strength of oven cured specimens at 28 days was about 2 times higher than that of ambient cured specimens. Increase in curing temperature from 60°C to 90°C, causes increase in compressive strength but not significantly.

Since the chemical reaction of heat cured geopolymer concrete is due to substantially fast polymerisation process, the compressive strength did not vary with the age of concrete. This observation is in contrast to the well-known behaviour of OPC concrete, which undergoes hydration process and hence gains strength over time.

TABLE 12
COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE AT VARIOUS AGES IN W/B 0.3

Comp strength	RHA Replacement level					
	5%			5%		
	Curing conditions			Curing conditions		
	Ambient	Oven curing @ 60°C	Oven curing @ 90°C	Ambient	Oven curing @ 60°C	Oven curing @ 90°C
7	4.56	22.80	23.48	3.36	19.06	18.80
14	7.81	25.30	26.82	5.48	20.13	21.10
28	16.43	28.40	30.15	14.26	23.40	22.90

TABLE 13
COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE AT VARIOUS AGES IN W/B 0.45

Comp.stght	RHA Replacement level					
	5%			5%		
	Curing conditions			Curing conditions		
	Ambient	Oven curing @ 60°C	Oven curing @ 90°C	Ambient	Oven curing @ 60°C	Oven curing @ 90°C
7	3.02	20.16	22.17	2.74	13.70	14.08
14	5.42	23.42	25.76	6.36	18.18	18.90
28	14.80	26.60	28.70	13.70	22.03	23.10

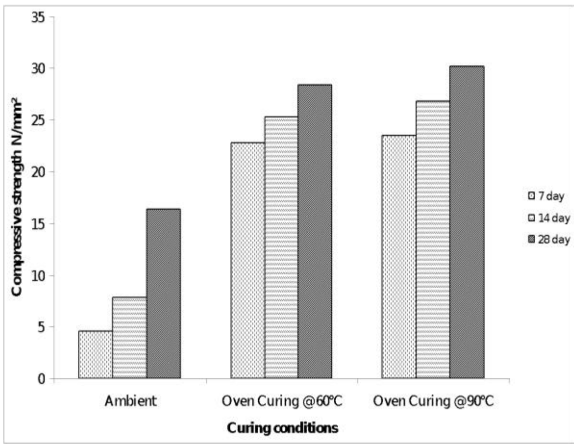

Fig 3 Compressive strength of geopolymer concrete for various curing
conditions at 0.3 activator solution to binder ratio @ 5 % RHAreplacement

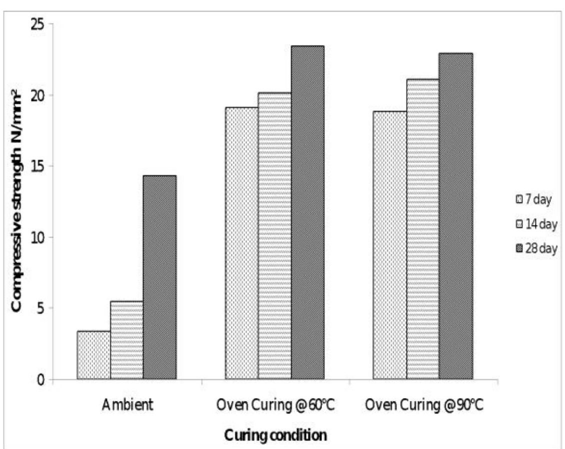

Fig 4 Compressive strength of geopolymer concrete for various curing
conditions at 0.3 activator solution to binder ratio @ 10% RHA replacement

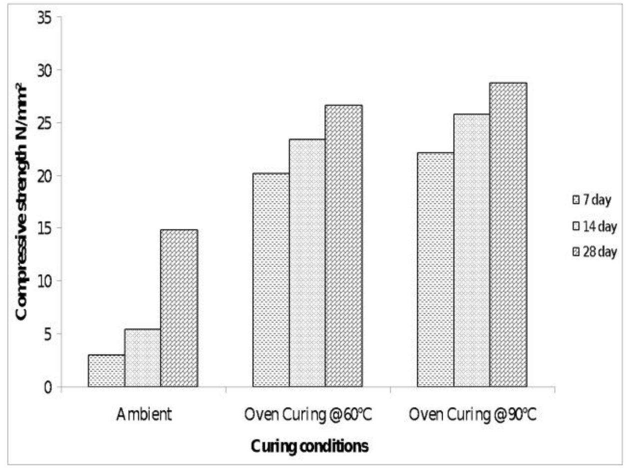

Fig 5 Compressive strength of geopolymer concrete for various curing
conditions at 0.45 activator solution to binder ratio @ 5% RHA replacement

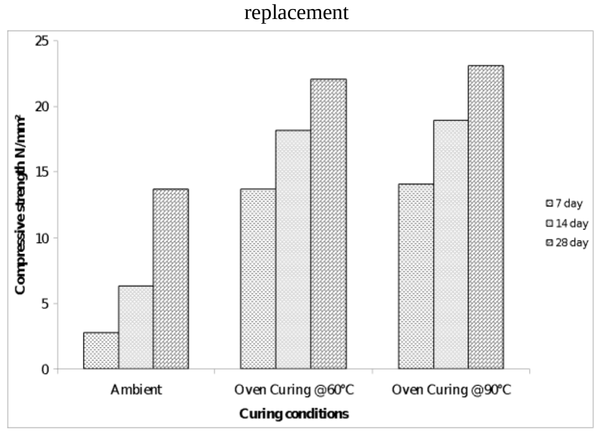

Fig 6 Compressive strength of geopolymer concrete for various curing
conditions at 0.45 activator solution to binder ratio @ 10% RHA replacement

a. Effect of Alkaline solution to binder ratio on strength

Effects of alkaline solution to binder ratio on compressive strength of geopolymer concrete are presented in Tables 14 & 15 and Fig 7 & 8. It is noted that in general the compressive strength marginally decreases with increase in alkaline solution to binder ratio from 0.30 to 0.45. Although the concentration of NaOH and the ratio of sodium silicate to NaOH are same, the content of fly ash decreases with increase in alkaline solution to binder ratio and which alters the compressive strength.

TABLE 14
COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE AT VARIOUS AGES FOR VARIOUS ACTIVATOR SOLUTIONS TO BINDER RATIO @ 5% RHA REPLACEMENT

Comp.stght	Activator solution/ binder					
	0.3			0.45		
	Curing conditions			Curing conditions		
	Ambient	Oven curing @ 60°C	Oven curing @ 90°C	Ambient	Oven curing @ 60°C	Oven curing @ 90°C
7	4.56	22.80	23.48	3.02	20.16	22.17
14	7.81	25.30	26.82	5.42	23.42	25.76
28	16.43	28.40	30.15	14.80	26.60	28.70

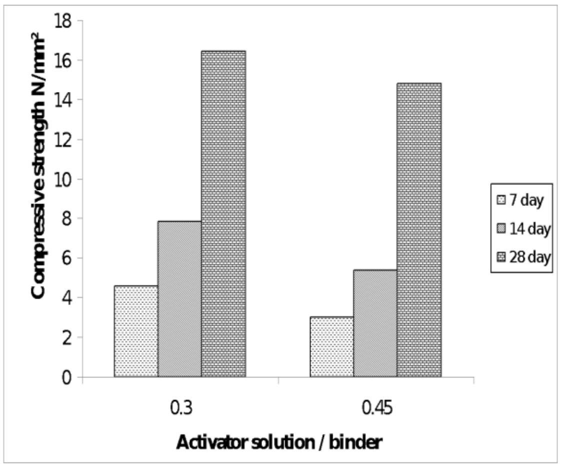

Fig 7 Compressive strength of geopolymer concrete for various activator solution to binder ratio at 5% RHA replacement for ambient curing

TABLE 15
COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE AT VARIOUS AGES FOR VARIOUS ACTIVATOR SOLUTIONS TO BINDER RATIO @ 10% RHA REPLACEMENT

Comp.stght	Activator solution/ binder					
	0.3			0.45		
	Curing conditions			Curing conditions		
	Ambient	Oven curing @ 60°C	Oven curing @ 90°C	Ambient	Oven curing @ 60°C	Oven curing @ 90°C
7	3.36	19.06	18.80	2.74	13.70	14.08
14	5.48	20.13	21.10	6.36	18.18	18.90
28	14.26	23.40	22.90	13.70	22.03	23.10

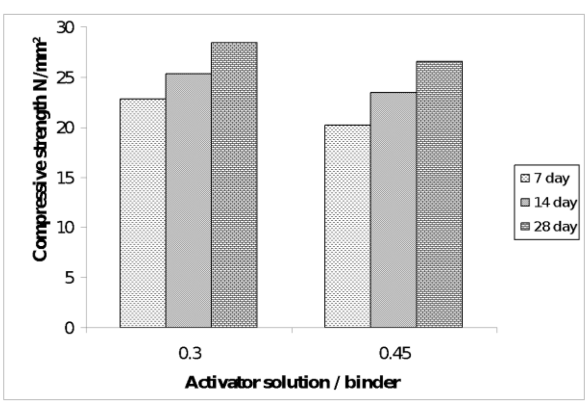

Fig 8 Compressive strength of geopolymer concrete for various activator solution to binder ratio at 5% RHA replacement for oven curing @ 60°C

b. Effect of water to geopolymer solids ratio on strength

In ordinary Portland cement (OPC) concrete, water in the mixture chemically reacts with the compounds of cement to produce C-S-H gel that binds the aggregates. In contrast, the water in a low calcium fly ash-based geopolymer concrete mixture does not cause a chemical reaction. In fact, the chemical reaction that occurs in geopolymers produces water that is eventually expelled from the binder. However, laboratory experience showed that water content in the geopolymer concrete mixture affected the properties of concrete in the fresh state as well as in the hardened state. In order to establish the effect of water content in the mixture, tests were performed.

The effect of water to geopolymer solids ratio are illustrated in Fig 9& 10 by plotting compressive strength of geopolymer concrete at various ages versus water to geopolymer solids ratio by mass. It demonstrates that the compressive strength of geopolymer concrete decreased as the ratio of water-to geopolymer solids by mass increased in small increments giving rise to more free water in the geopolymer concrete leading to a more porous microstructure. The trends of these test results are similar to those observed by Hardjito et al (2004) and Barbosa et al (2000) for their tests on geopolymer concretes.

TABLE 15
COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE AT VARIOUS AGES FOR VARIOUS TO GEOPOLYMER SOLID RATIO @ 5% RHA REPLACEMENT

Comp.stght	Water to geopolymer solids ratio					
	0.28			0.29		
	Curing conditions			Curing conditions		
	Ambient	Oven curing @ 60°C	Oven curing @ 90°C	Ambient	Oven curing @ 60°C	Oven curing @ 90°C
7	4.56	22.80	23.48	3.02	20.16	22.17
14	7.81	25.30	26.82	5.42	23.42	25.76
28	16.43	28.40	30.15	14.80	26.60	28.70

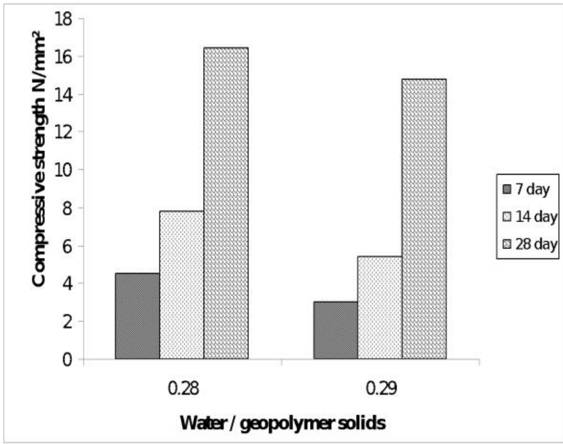

Fig 9 Compressive strength of geopolymer concrete for various water to geopolymer solid ratio at 5% RHA replacement for ambient curing

TABLE 16
COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE AT VARIOUS AGES FOR VARIOUS TO GEOPOLYMER SOLID RATIO @ 10% RHA REPLACEMENT

Comp.st ght	Water to geopolymer solids ratio					
	0.28			0.29		
	Curing conditions			Curing conditions		
	Ambie nt	Oven curin g @ 60°C	Oven curin g @ 90°C	Ambie nt	Oven curin g @ 60°C	Oven curin g @ 90°C
7	3.36	19.0 6	18.8 0	2.74	13.7 0	14.0 8
14	5.48	20.1 3	21.1 0	6.36	18.1 8	18.9 0
28	14.26	23.4 0	22.9 0	13.70	22.0 3	23.1 0

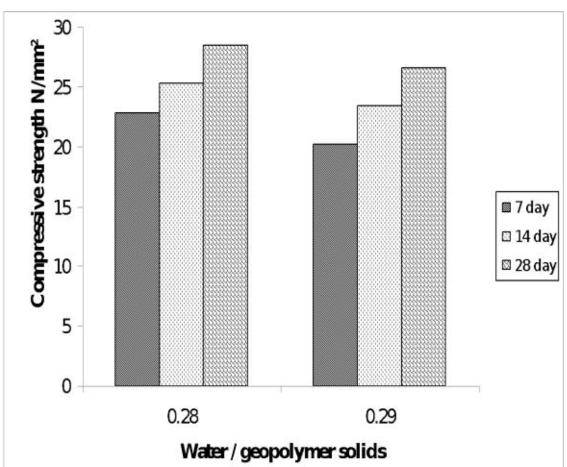

Fig 10 Compressive strength of geopolymer concrete for various water to geopolymer solid ratio at 5% RHA replacement for oven curing @ 60°C

c. Effect of RHA on strength

Various researchers revealed that there is low rate of strength development of geopolymer concrete at ambient curing conditions. While rapid strength development is often cited as an advantage of alkali activation processes, this could be possible by more heat treatment. It is possible to hasten strength development by adding other hydraulic binders such as GGBS, RHA etc,. Compressive strength of geopolymer concrete with 5 and 10% of partial replacement are presented in Tables 17 & 18 and depicted in Fig 11 & 12. Increase in RHA content causes decrease in compressive strength irrespective of age. RHA having higher percentage of silica content with minor traces of alumina content does not participate effectively in the polymerization process. When the partial replacement of RHA increases, silica to alumina ratio is increased in the concrete mixture and hence affects the compressive strength of geoploymer concrete.

TABLE 17
COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE AT VARIOUS AGES FOR VARIOUS RHA REPLACEMENT LEVELS WITH ALKALINE SOLUTION /BINDER RATIO OF 0.30

Comp.stg ht	RHA Replacement level					
	5%			5%		
	Curing conditions			Curing conditions		
	Ambien t	Oven curin g @ 60°C	Oven curin g @ 90°C	Ambien t	Oven curin g @ 60°C	Oven curin g @ 90°C
7	4.56	22.80	23.48	3.36	19.06	18.80
14	7.81	25.30	26.82	5.48	20.13	21.10
28	16.43	28.40	30.15	14.26	23.40	22.90

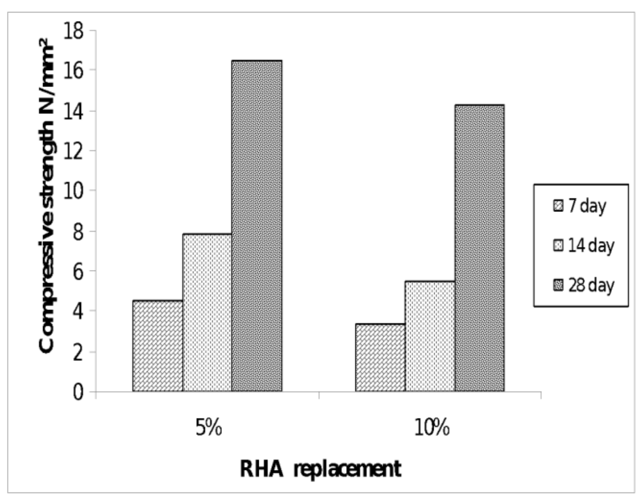

Fig 11 Compressive strength of geopolymer concrete for various RHA replacement at 0.3 activator solution / binder ratio for ambient curing

TABLE 18
COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE AT VARIOUS AGES FOR VARIOUS RHA REPLACEMENTS WITH ACTIVATOR SOLUTION / BINDER RATIO OF 0.45

Comp.stght	RHA Replacement level					
	5%			5%		
	Curing conditions			Curing conditions		
	Ambient	Oven curing @ 60°C	Oven curing @ 90°C	Ambient	Oven curing @ 60°C	Oven curing @ 90°C
7	3.02	20.16	22.17	2.74	13.70	14.08
14	5.42	23.42	25.76	6.36	18.18	18.90
28	14.80	26.60	28.70	13.70	22.03	23.10

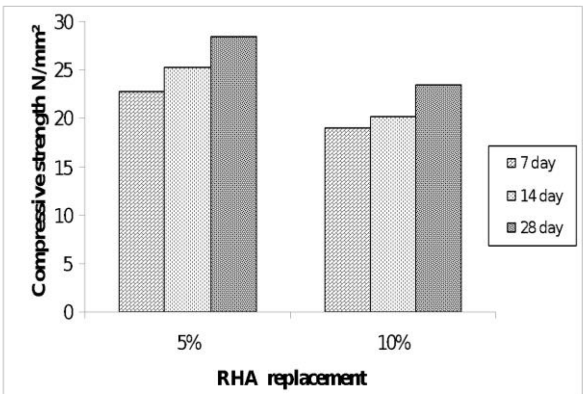

Fig 12 Compressive strength of geopolymer concrete for various RHA replacement at 0.3 activator solution / binder ratio for oven curing @ 60°C

VI. CONCLUSION

- Fly ash-RHA based geopolymer concrete cured in the laboratory ambient conditions gains compressive strength with age.
- The compressive strength of heat cured specimens does not depend on age.
- There is no substantial gain in the compressive strength of heat cured fly ash based geopolymer concrete with age beyond 7 days.
- Compressive strength of oven cured specimens at 28 days was about 2 times higher than that of ambient cured specimens.
- Increase in curing temperature from 60°C to 90°C, causes marginal increase in compressive strength.
- Compressive strength of geopolymer concrete decreases with increase in alkaline solution to binder ratio irrespective of curing conditions, age and RHA level.
- As the ratio of water to geopolymer solids by mass increases, the compressive strength of geopolymer concrete decreases. This allows more entrapment of water within the geopolymer paste and makes a poorer microstructure in the concrete.
- The maximum compressive strength achieved in this project work for fly ash—RHA based geopolymer concrete is 30.15MPa.
- Addition of RHA to fly ash tends to decrease the compressive strength of geopolymer concrete.
- RHA alone could not be used as source material for the production of geopolymer concrete.

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